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Patent Application

Attorney Docket No.: 45051-6 USPX

IN THE UNITED STATES PATENT AND TRADEMARK OFFICE

Applicant: Niklas STENSROM et al.

Serial No. 09/718,667

Filed: November 22, 2000

For: DIGITAL COMMUNICATION RECEIVER AND A METHOD FOR THE  
OPERATION THEREOF

Group No. 2631

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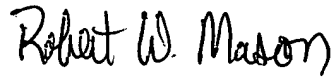
CLAIM OF PRIORITY UNDER 35 U.S.C. § 119

Under the provisions of 35 U.S.C. §119 Applicants hereby claim the priority of Swedish  
patent application No. 9904281-4 as filed on November 25, 1999, which is identified in the  
declaration of the above-identified application. A certified copy of the priority document is filed  
herewith.

Patent Application  
Attorney Docket No.: 45051-6 USPX

Applicants believe that no further information or documentation in support of its priority claim will be required.

Respectfully submitted,



Robert W. Mason  
Reg. No.: 42,848

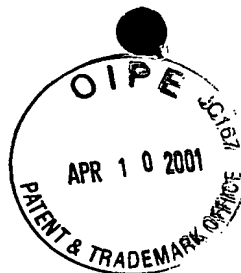
Submitted: April 9, 2001

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(21) Patentansökningsnummer      9904281-4  
Patent application number

(86) Ingivningsdatum                      1999-11-25  
Date of filing

Stockholm, 2001-01-09

För Patent- och registreringsverket  
For the Patent- and Registration Office

*Åsa Dahlberg*

Åsa Dahlberg

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Initial Patent only registered

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Huvudförfattare: Kassar

## A DIGITAL COMMUNICATION RECEIVER AND A METHOD FOR THE OPERATION THEREOF

### 5 Technical Field

The present invention relates to digital communication receivers of the type, which is adapted to communicate with a digital communication transmitter across a communication channel and which comprises a channel estimator for providing a channel estimate of the communication channel based on a received signal, an equalizer for estimating a sequence of transmitted symbols and providing a sequence of decided symbols based on the received signal and the channel estimate, and a channel tracker for producing an updated channel estimate based on the received signal and the decided symbols and for supplying the updated channel estimate to the equalizer. The invention is also directed at a wireless communication device, for instance a radio telephone, incorporating such a digital communication receiver, for instance a TDMA receiver.

Moreover, the present invention relates to a method of operating a digital communication receiver, where a channel estimate of a communication channel between the receiver and a corresponding communication transmitter is produced from a received signal, and where a sequence of decided symbols is produced from the received signal and the channel estimate.

### Description of the Prior Art

Digital communication receivers as set out above are widely used in modern communication systems. For instance, most modern systems for mobile or cellular telecommunication are based on digital communication, GSM and EDGE being two well-known examples. In a digital communication system, the digital communication receiver necessarily requires a considerable level of complexity in order to be able to



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synchronization position to a channel estimator 130. The channel estimator 130 is arranged to determine an estimate,  $H$ , of the radio channel.

As a next step, the received baseband signal  $y_c$ , the channel estimate  $H$  and the synchronization position are all supplied to an equalizer 140, which - based on a predetermined channel model - demodulates the received signal  $y_c$  in order to estimate the transmitted data. The channel model may for instance be expressed as:

$$y_c = H^T U_c + e_c,$$

where  $H = [h_0, \dots, h_L]^T$  are complex-valued channel filter taps,  $U_c = [u_c, \dots, u_{c-L}]^T$  are a vector with the transmitted symbols, and  $e_c$  represents noise. This channel model is further described in *Digital Communications*, by J. Proakis, Mc Graw-Hill, New York, 1995, which is fully incorporated herein by reference.

In other words, the equalizer 140 is arranged to estimate the transmitted symbols,  $u_c$ . The equalizer 140 provides as a first output a sequence of decided symbols  $\hat{u}_c$  and as a second output a qualitative information  $M_c$  (labelled Metric in FIG 1), which is a measure of how close to the transmitted symbols the estimated symbols are. This qualitative information will be used when the received signal is processed further. Commonly, the qualitative information,  $M_c$ , is based on a squared distance between the received sequence and the predicted received sequence given the decided symbols, i.e.:

$$M_c = |y_c - \hat{y}_c|^2 = |y_c - H^T \hat{U}_c|^2,$$

where  $\hat{U}_c = [\hat{u}_c, \dots, \hat{u}_{c-L}]^T$  is a vector with the decided symbols. It is observed that if  $M_c$  has a small value, then the estimated channel  $H \approx$  the real channel  $H_{real}$ , i.e. the estimated channel filter taps are essentially correctly estimated, and furthermore  $U = U_{transmitted}$ , i.e. the estimated symbols are correct.

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The procedure above exhibits good performance, if the host communication device is not moving too rapidly. Under such conditions, a reasonably valid assumption is that the channel filter taps  $H$  are constant during one burst of transmitted information. However, when the velocity of the host communication device increases, the radio channel starts changing over the burst, which means that the channel estimate obtained by way of the training sequence will not be valid for the entire data sequence within the burst. For instance, for a TDMA receiver used in GSM, where GMSK modulation is utilized on the 1800 MHz band, performance starts to degrade, when the velocity of the host communication device increases above 100 - 200 kmph. In an EDGE system, where 8-PSK modulation is utilized, which is more sensitive to distortions than GMSK modulation, at the same frequency, performance starts to degrade already at velocities around 50 kmph. Thus, in order to handle this problem, a channel tracker is required.

A previously known TDMA receiver architecture with a channel tracker is shown in FIG 2. As for FIG 1, the burst received by the antenna 1 is converted to a received baseband signal  $y_r$  by a front-end receiver 210. The received signal is correlated with the known training sequence by a synchronizer 220 in order to find the synchronization position, and then the channel is estimated by a channel estimator 230 in correspondence with what has been described above for channel estimator 130 of FIG 1.

The channel estimate  $H_0$  is an initial estimate, which is used to start up an equalizing process performed by an equalizer 240. As has already been described above with reference to FIG 1, the equalizer 240 estimates a sequence of decided symbols  $\hat{u}_t$  as well as qualitative information (Metric). The decided symbols  $\hat{u}_t$  are supplied together with the received signal  $y_r$  to a channel tracker 250, which updates the channel estimate  $H_t$  for each time instant  $t =$

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1, ..., N, where N is the duration of the burst. The channel estimate  $H_i$  is subsequently fed back to the equalizer 240, which will use the updated channel estimate in order to demodulate  $\hat{u}_{i+1}$ , and so on.

5 By using a channel tracker 250, problems can be managed, that are otherwise associated with host communication devices travelling at high velocities. However, the channel tracker 250 of the prior art receiver shown in FIG 2 is used constantly during all operational times, which  
10 means that a lot of unnecessary data processing is performed by the receiver, even when the velocity of the host communication device is low and good performance may be obtained without using a channel tracker. Moreover, since the channel tracker 250 is used all the time, the  
15 current consumption is undesiredly high for a previously known receiver, like the one illustrated in FIG 2.

#### Summary of the Invention

20 It is an object of the present to provide an improvement to digital communication receivers as described above in terms of current efficiency, inter alia.

The above object has been achieved by the provision of a controller, which determines and evaluates the momentary quality of the communication channel and in  
25 response generates a control signal, which is used for enabling or disabling the channel tracker in a way, so that the channel tracker is only active in circumstances, where so is needed (when the quality of the communication channel is degraded due to e.g. high-velocity movement of the  
30 digital communication receiver).

Thus, according to the invention the channel tracker is turned on or off based on the current radio channel conditions. The decision whether to turn the channel tracker on or off may be based on the qualitative  
35 information output from the equalizer. The decision may



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alternatively be based on a comparison between new channel estimates at the end and/or at the beginning of a burst and an initial channel estimate. By using the channel tracker only when necessary, processing power consumed by the receiver can be reduced, thereby allowing longer operational times between battery chargings in a portable host processing device, such as a mobile or cellular radio telephone.

Other objects, advantages and features of the present invention will appear from the following detailed disclosure of preferred and alternate embodiments, from the appended claims as well as from the drawings.

#### Brief Description of the Drawings

The present invention will now be described in more detail with reference to a preferred and an alternate embodiment in conjunction with the attached drawings, in which:

FIGs 1 and 2 are illustrations of two communication receivers of the prior art,

FIG 3 is a schematic block diagram illustrating a digital communication receiver according to a preferred embodiment,

FIG 4 is a schematic block diagram illustrating a digital communication receiver according to an alternate embodiment, and

FIG 5 is a triple-graph diagram illustrating the typical appearance of the qualitative information output from the equalizer of the receiver in three different situations.

#### Detailed Disclosure of Embodiments

Referring first to FIG 5, it is observed that the behavior of the qualitative information output ( $M_t$ , Metric) of the equalizer depends on which kind of distortion, that

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is affecting the received signal  $y_t$ . Three different typical behaviors of the qualitative information are shown for a receiver without any channel tracker (i.e. like the one illustrated in FIG 1) for three different scenarios.

- 5 The fact that the receiver has no channel tracker means that the channel estimate obtained during the training sequence will be used for the entire burst.

The uppermost graph of FIG 5 illustrates a scenario, where white noise represents the dominating distortion. It appears that the qualitative information is quite constant during both the training sequence (TS) and the information sequence (Data).

10 In the second graph, the dominating distortion originates from a co-channel interferer, i.e. a remote transmitter, which is transmitting on the same carrier frequency. Since the co-channel interferer might not be synchronized with the desired signal, only some part of the burst may be distorted (in FIG 5, the rightmost portion of the second graph).

20 In the lowermost graph of FIG 5, the distortion is due to high velocity of the host communication device, implying that the communication channel is time-varying and changing over the burst. Since the channel taps,  $H$ , used in the equalizer are estimated during the training sequence and are therefore optimized for the center of the burst (in the example shown in FIG 5), the qualitative information increases at the end of the burst. This behavior of the qualitative information can be used according to the invention for determining whether the channel tracker needs to be enabled or not.

30 FIG 3 illustrates a digital communication receiver according to a preferred embodiment of the invention.

In similarity with the prior art receivers shown in FIGs 1 and 2, the digital communication receiver 300 is connected to an antenna 1 for receiving a radio or micro-

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5 wave signal transmitted by a digital communication trans-  
mitter. The radio or microwave signal is supplied to a  
front-end receiver 310, which converts the signal down to a  
received baseband signal  $y_t$ , in similarity with what has  
10 been described above with reference to FIGs 1 and 2. The  
front-end receiver 310 comprises various components known  
per se, such as filters, amplifiers, local oscillators and  
mixers, all of which are well-known to a man skilled in the  
art. Consequently, the internal structure of the front-end  
15 receiver 310 is not dealt with further herein.

The received signal  $y_t$  is supplied to a synchronizer  
320, which correlates a known training sequence with the  
received signal  $y_t$  containing the same training sequence,  
wherein the synchronizer 320 is able to locate the  
15 synchronization position. The received signal  $y_t$  is  
supplied together with the synchronization position to a  
channel estimator 330, which estimates the channel,  $H$ , in a  
way essentially similar to what has been described with  
reference to FIGs 1 and 2.

20 The received signal  $y_t$ , the channel estimate  $H$ , and  
the synchronization position are then supplied to an  
equalizer 340, which modulates the received signal in order  
to obtain the transmitted data. As was described already  
with reference to FIGs 1 and 2, the equalizer 340 provides  
25 a first output in the form of a sequence of decided symbols  
 $\hat{u}_t$  and a second output in the form of a qualitative  
information (Metric).

The decided symbols  $\hat{u}_t$  are supplied together with the  
received signal  $y_t$  to a channel tracker 350, which will  
30 update the channel estimate  $H_t$  for each time instant  
 $t = 1, \dots, N$ , where  $N$  is the duration of the burst. The  
updated channel estimate  $H_t$  is then fed back to the  
equalizer 340 through a switch 360, on condition that the  
switch 360 assumes a closed position. As will be described  
35 below, the switch 360 is controllable through a controller

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370. If an updated channel estimate  $H_t$  is in fact fed back through the closed switch 360 to the equalizer 340, the equalizer 340 will use the updated channel estimate  $H_t$  when demodulating  $\hat{u}_{t+1}$ , and so on.

5 As mentioned above, a controller 370 is provided in the communication receiver 300 shown in FIG 3. The controller 370 has a first input for receiving an updated channel estimate  $H_t$  from the channel tracker 350. The controller 370 also has a second input for reading the  
10 qualitative information Metric provided by the equalizer 340. Based on the qualitative information, the controller 370 determines and evaluates the quality of the communication channel in order to decide whether the channel tracker 350 needs to be used or not. To this end, the channel  
15 tracker 350 is enabled and disabled, respectively, via a control signal from the controller 370 (labelled "Tracker y/n?" in FIG 3). In the preferred embodiment of Fig 3, this control signal is given a first value when the channel tracker 350 is to be enabled, and a second value when the  
20 channel tracker 350 is to be disabled.

The controller 370 is provided with a memory for storing a predetermined upper limit for the qualitative information (Metric) from the equalizer 350, wherein this upper limit defines an acceptable limit for a difference,  
25 preferably a squared distance as described above, between symbols in the received signal ( $y_t$ ) and symbols in a predicted received signal given the decided symbols ( $\hat{u}_t$ ). In other words, the qualitative information is representative of a degree of correspondence between the received  
30 signal and the decided symbols, and the controller 370 uses the predetermined upper limit as a criterion for determining whether the qualitative information does not meet this criterion, and consequently, whether the control signal "Tracker y/n?" will have to be given its first

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value, indicating that the channel tracker 350 needs to be enabled.

The controller 370 may be realized as a programmable microprocessor, a programmable logic array, other logic circuitry, discrete logic gates and components, etc.

In the communication receiver 300 shown in FIG 3, assuming that the channel tracker 350 has been enabled at some previous moment of time by the controller 370, the controller 370 is also adapted to determine whether the channel tracker 350 may be disabled (turned off). In this case, it is less suitable to use the above qualitative information produced by the equalizer 340, since the channel tracker 350 will try to follow the variations in the communication radio channel, implying that the qualitative information produced by the equalizer 340 will be approximately constant during the entire burst. Instead, the channel estimates  $H_t$  are supplied to the control unit 370, which will use these for determining whether the channel tracker 350 may be turned off or not. For instance, if  $H_0 \approx H_{\text{start}} \approx H_{\text{end}}$ , where  $H_0$  is the initial channel estimate and  $H_{\text{start}}$ ,  $H_{\text{end}}$  are the channel estimates at the beginning and the end of the burst, respectively, then the quality of the radio channel is acceptable, and the controller 370 determines that the channel tracker 350 may be turned off or disabled by giving the control signal "Tracker y/n?" a second value, as previously described.

On the other hand, if  $||H_0 - H_{\text{start}}|| \gg 0$  and  $||H_0 - H_{\text{end}}|| \gg 0$ , the controller 340 decides to continue using the channel tracker 350 and, consequently, gives the control signal "Tracker y/n?" its first value, as previously described. The control signal "Tracker y/n?" is also supplied to the switch 360 for setting it to an open and closed position, respectively.

Referring now to FIG 4, an alternate embodiment of the communication receiver 400 is shown. The antenna 1,

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front-end receiver 410, synchronizer 420, channel estimator 430, equalizer 440 and channel tracker 450 are all essentially identical to the antenna 1, front-end receiver 310, synchronizer 320, channel estimator 330, equalizer 340 and channel tracker 350 of FIG 3, and the description thereof is not repeated now.

In contrast to FIG 3, on the other hand, the communication receiver 400 of FIG 4 does not use the qualitative information, Metric, when determining whether the channel tracker 350 is to be enabled or disabled. Instead, the decided symbols,  $\hat{u}_i$ , are supplied to a second channel estimator 480. Based on the decided symbols at the beginning and the end of the burst, new channel estimates,  $H_{start}$  and  $H_{end}$ , are obtained by the second channel estimator 480 and submitted to the controller 470. If  $||H_0 - H_{start}|| \gg 0$  and  $||H_0 - H_{end}|| \gg 0$ , the controller 470 decides to enable the channel tracker 450 by providing its control signal "Tracker y/n?" with a first value, wherein the channel tracker 450 will be ready to be used when the next burst is received. The decision whether to turn the channel tracker 450 off is made in essentially the same way, as has been described above with reference to FIG 3.

The digital communication receivers 300 and 400 shown in FIGs 3 and 4 are particularly well adapted to be incorporated in a portable radio telephone, such as a GSM mobile telephone. Alternatively, a digital communication receiver according to the invention may very well be incorporated in a base station in a mobile telecommunication system, such as a GSM base station. However, the present invention is not limited to these examples, and the digital communication receiver according to the invention may be incorporated in virtually any host communication device. Other embodiments than the ones described above are equally applicable within the scope of the invention, as defined by the appended independent claims.

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## CLAIMS

1. A digital communication receiver (300, 400)  
5 adapted to communicate with a digital communication transmitter across a communication channel, the digital communication receiver comprising:  
a channel estimator (330, 430), adapted to provide a  
channel estimate ( $H_t$ ) of the communication channel based on  
10 a received signal ( $y_t$ ),  
an equalizer (340, 440), adapted to estimate a  
sequence of transmitted symbols ( $u_t$ ) and provide a sequence  
of decided symbols ( $\hat{u}_t$ ) based on the received signal and  
the channel estimate, and  
15 a channel tracker (350, 450), adapted to produce an  
updated channel estimate ( $H_t$ ) based on the received signal  
( $y_t$ ) and the decided symbols ( $\hat{u}_t$ ), and adapted to supply  
the updated channel estimate to the equalizer,  
characterized by  
20 a controller (370, 470), which is adapted to deter-  
mine and evaluate a quality of the communication channel  
and in response generate a control signal ("Tracker y/n?")  
for enabling the channel tracker to produce said updated  
channel estimate ( $H_t$ ).  
25
2. A digital communication receiver as in claim 1,  
wherein the controller (370, 470) is adapted to determine  
whether or not the decided symbols ( $\hat{u}_t$ ) from the equalizer  
(340, 440) and/or the updated channel estimate ( $H_t$ ) from  
30 the channel tracker (350, 450) meet(s) predetermined  
criteria, and in response generate the control signal  
("Tracker y/n?").
3. A digital communication receiver as in claim 1 or  
35 2, wherein the controller (370) is adapted to receive  
qualitative information (Metric), which is produced by the







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How to use the system

## ABSTRACT

A digital communication receiver (300) communicates with a digital communication transmitter across a communication channel and has: a channel estimator (330), which provide a channel estimate ( $H_c$ ) of the communication channel based on a received signal ( $y_c$ ); an equalizer (340), which estimates a sequence of transmitted symbols ( $u_c$ ) and provides a sequence of decided symbols ( $\hat{u}_c$ ) based on the received signal and the channel estimate; and a channel tracker (350), which produces an updated channel estimate ( $H_c$ ) based on the received signal ( $y_c$ ) and the decided symbols ( $\hat{u}_c$ ), and which supplies the updated channel estimate to the equalizer. The digital communication receiver (300) also has a controller (370), which determines and evaluates a quality of the communication channel and in response generates a control signal ("Tracker y/n?") for enabling the channel tracker to produce the updated channel estimate ( $H_c$ ).

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To be published together with FIG 3.

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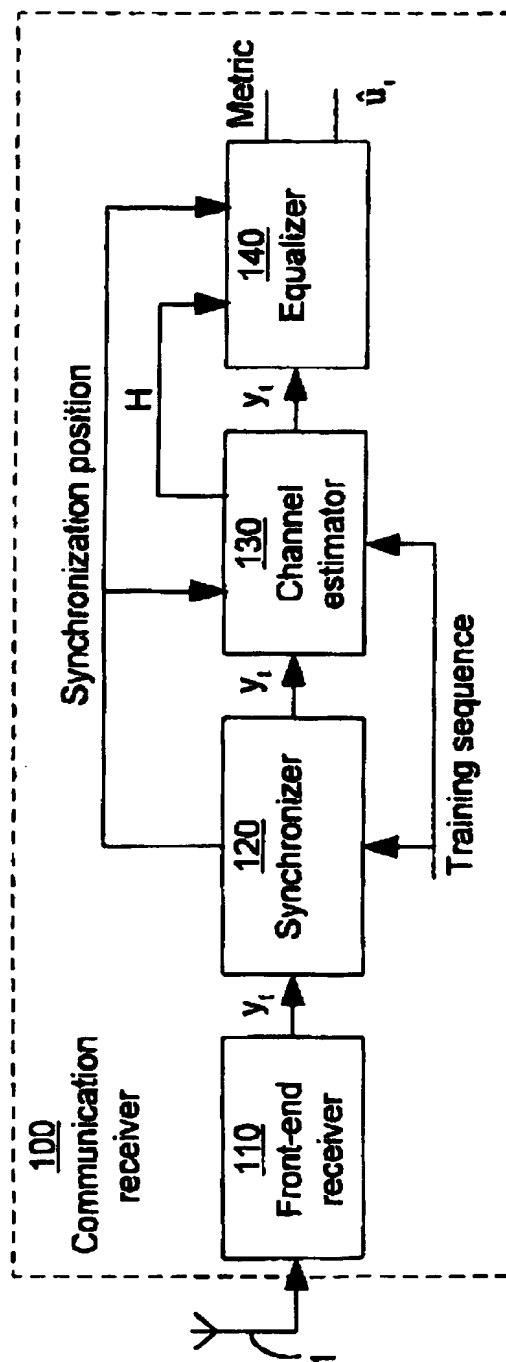
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FIG 1

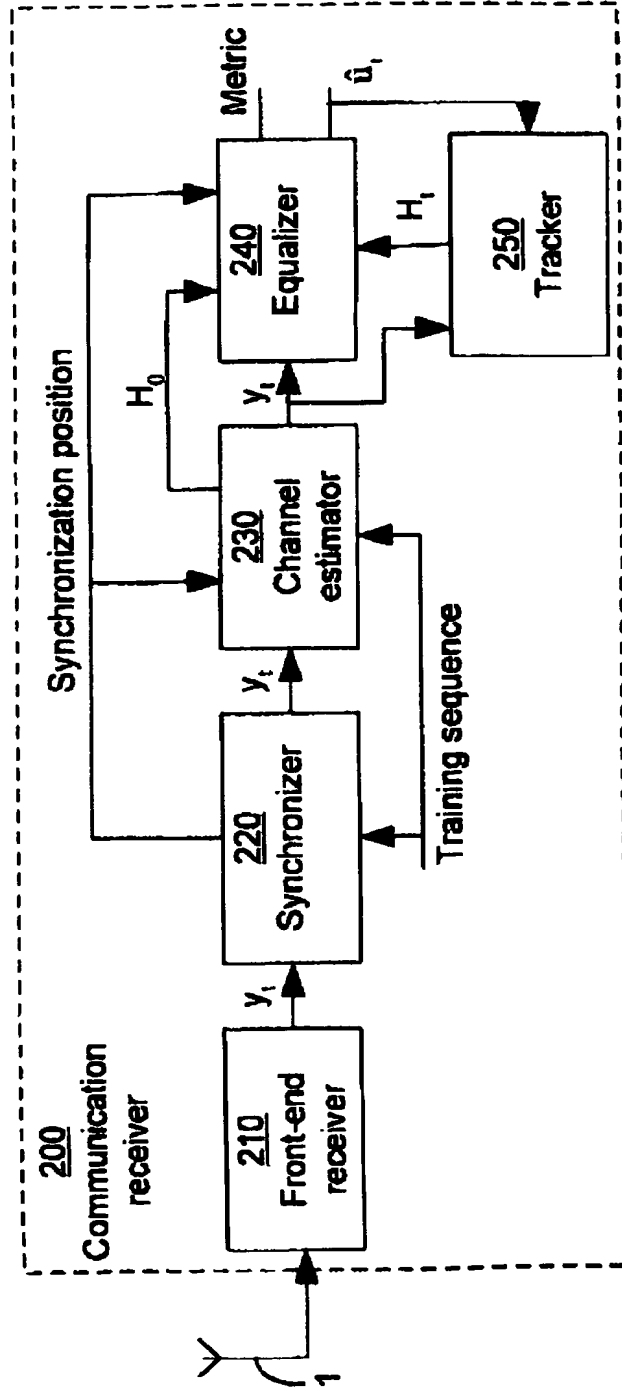
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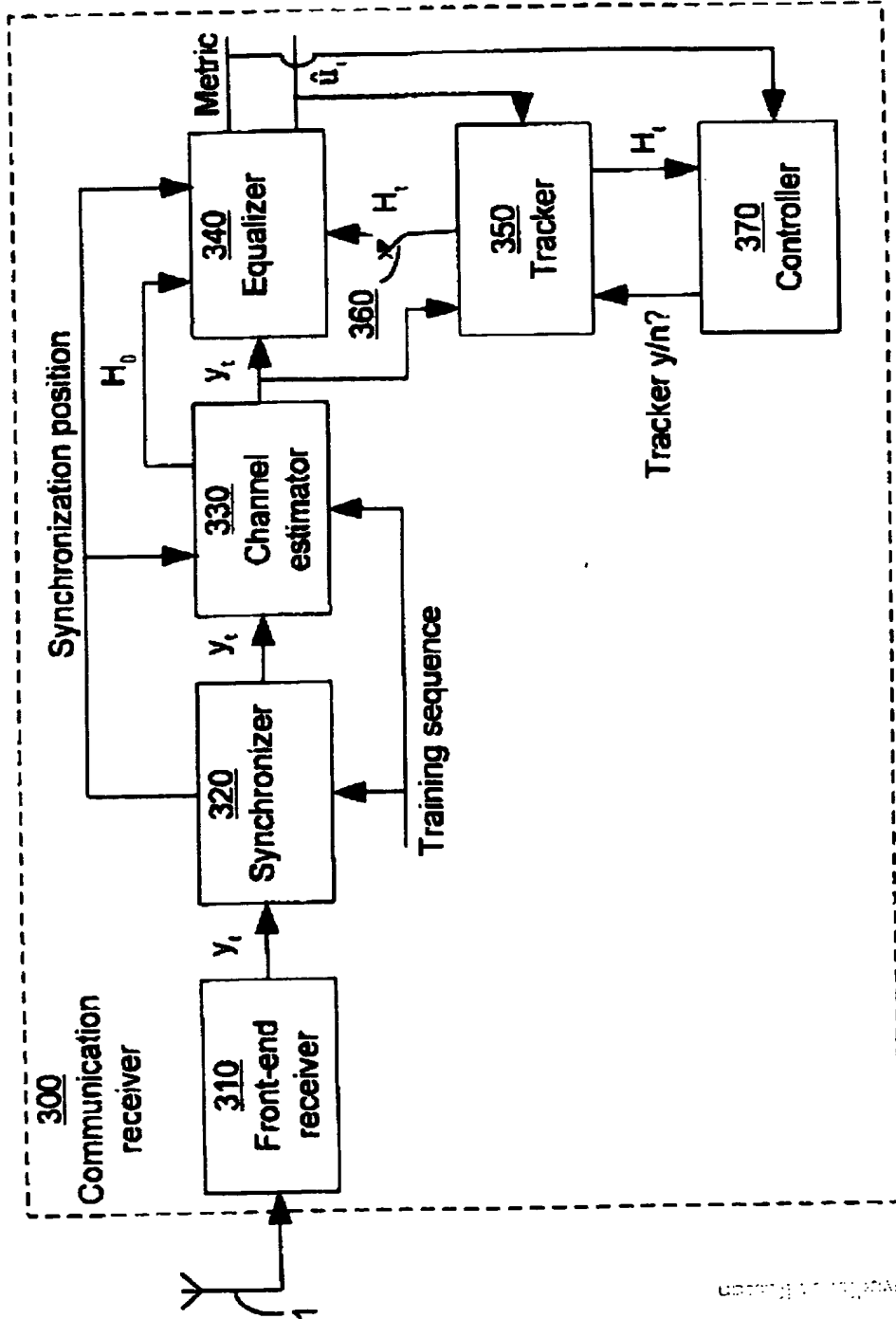
FIG 2

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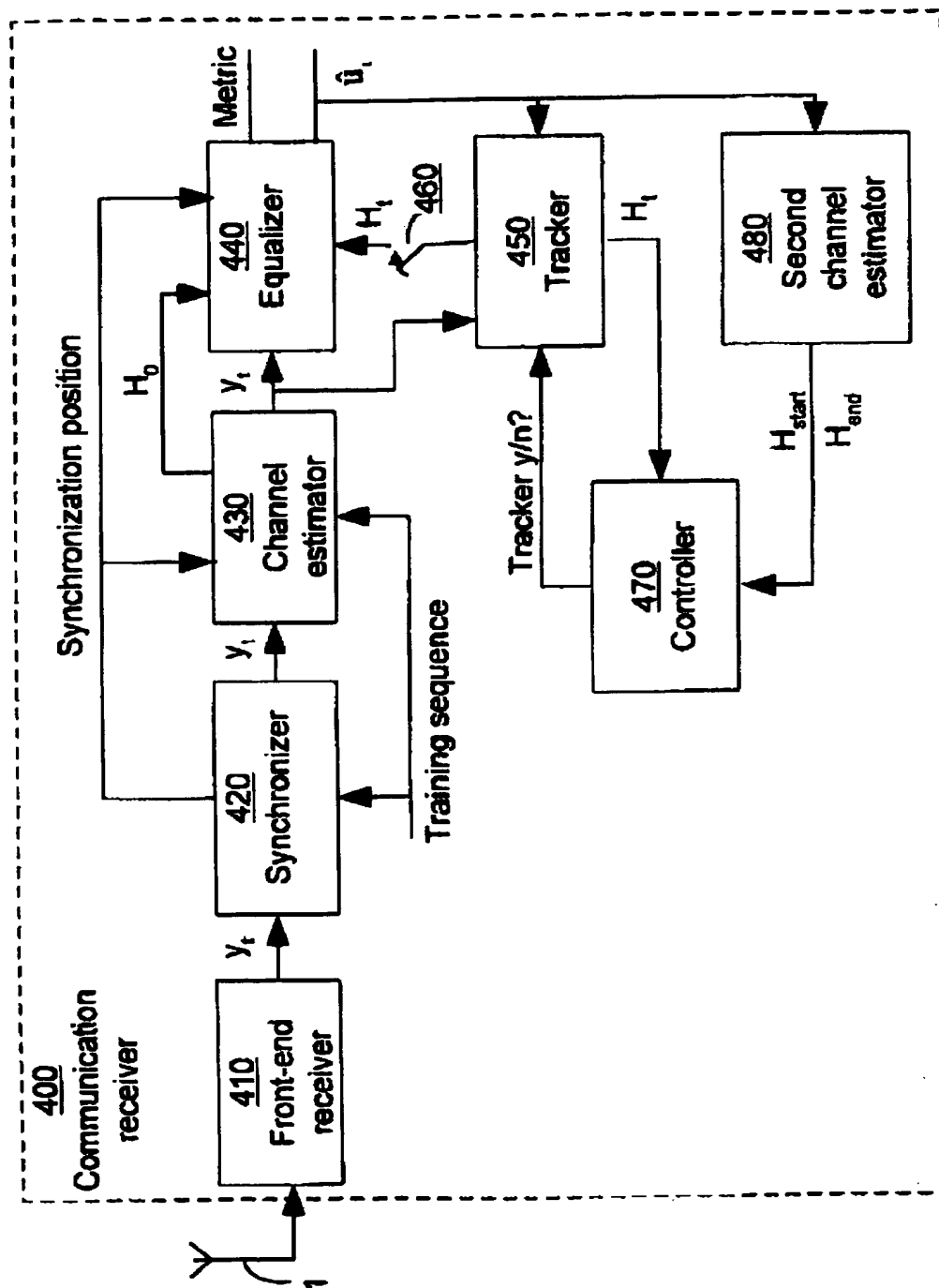
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FIG 3



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FIG 4



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## Typical TDMA burst

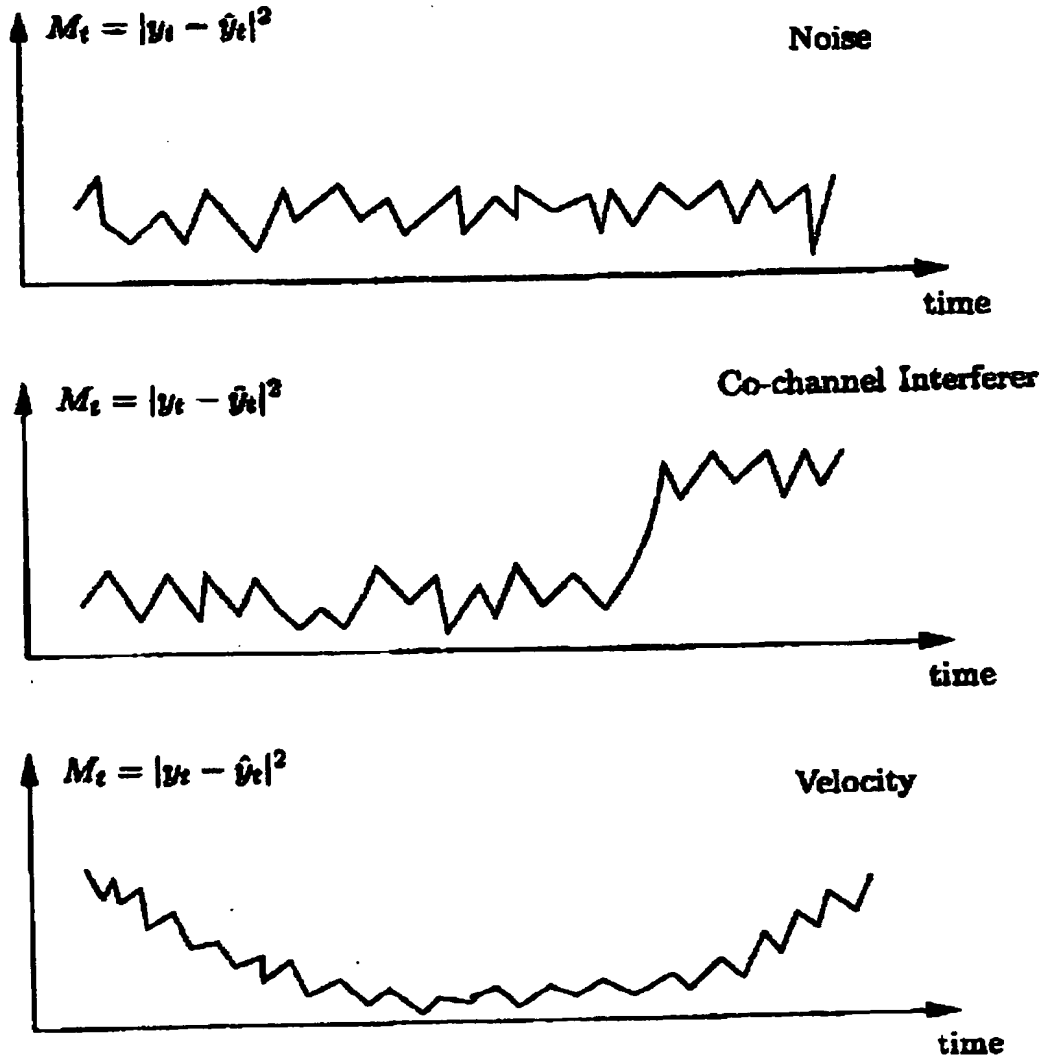
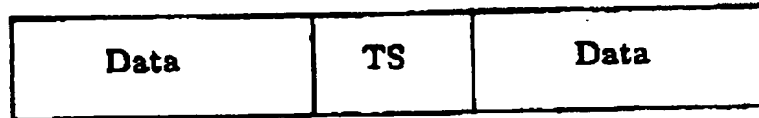


FIG 5